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APPLICATION FOR

UNITED STATES LETTERS PATENT

FOR

SEISMIC SENSING APPARATUS AND METHOD WITH HIGH-G SHOCK ISOLATION

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Background of the Invention

1. Field of the Invention

This invention relates generally to geologic survey sensors and more particularly to seismic sensors.

2. Description of the Related Art

Oil and gas exploration includes the acquisition of formation characteristics by conducting seismic surveys. When seismic surveys are conducted on land, sensors are positioned in a survey area. Well-known techniques such as using vibrator trucks or explosives are employed to generate an acoustic wave. The acoustic wave travels through earth formations and is partially reflected at formation discontinuities. Various sensor types are used to sense the reflected wave as it returns to the surface. The senor outputs a signal indicative of the wave, and a surface controller is then typically used to record the signal.

A typical sensor used is a velocity sensor, also known in the art as a geophone. A velocity sensor is a spring-mass sensor that uses relative motion between a mass and a coil to generate an analog output signal. When an acoustic wave contacts the sensor, the sensor housing moves. An internal mass suspended by a spring within the housing, tends to remain motionless as the housing moves relative to the internal mass. In a geophone, the internal mass is

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an electrically conductive coil having output leads and the housing contains an attached magnet. The relative motion of the magnet with respect to the coil produces a voltage output on the output leads. The resultant voltage produced is proportional to the velocity of the relative motion.

An alternative to the velocity-type geophone is an acceleration sensor called an accelerometer. Recent advances in accelerometer technology have resulted in the development of micro-electromechanical systems ("MEMS") based accelerometers. These MEMS accelerometers have been used in seismic sensor modules with some performance features comparable to a geophone-based module.

A drawback of a typical MEMS sensor module is that the module is sensitive to large amplitude, short period mechanical shock known as high-g shock inputs. Such inputs are commonly encountered during handling of seismic equipment in the field during transportation and insertion ("planting") of sensor modules in the ground. These high-g shocks are typically two and one half orders of magnitude larger than seismic energy sensed by the accelerometer, which may damage or destroy accelerometers housed in the modules. High-g as used herein is distinguished from sub-g, which is defined as any input force less than 1g (1x the force due to gravity).

Another problem encountered in a typical accelerometer is certain noise encountered during operation caused by resonances of the module structure. There is a need for a seismic sensor having noise abatement capability for noise created by system resonance.

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Summary of the Invention

The present invention described below addresses some or all of the drawbacks described above by providing a seismic sensor having single or multi-axis sensitivity and which can withstand high-g shock during handling and transport, and which can subsequently reduce module noise while measuring sub-g acoustic waves when the module is planted.

In one aspect of the invention, an apparatus for sensing seismic waves in the earth is provided. The apparatus includes a housing with one or more seismic sensors disposed in the housing. At least one isolator is coupled to the one or more seismic sensors for isolating the one or more seismic sensors from high-g shock induced in the housing.

In another aspect of the invention, a seismic sensor module tolerant to high-g shock inputs is provided. The module comprises a module case and a sensor assembly housed by the module case. An inertial mass is coupled to at least one seismic sensor in the sensor assembly, and at least one isolator is coupled to the sensor assembly and the module case.

Another aspect of the invention provides a seismic sensor module that comprises a module case and a sensor assembly coupled to the module case. The sensor assembly includes at least one seismic sensor, and an inertial mass is coupled to the sensor assembly.

A sensor module tolerant to high-g shock inputs is provided in another aspect of the invention, wherein the module comprises a module case and a

sensor assembly within the module case. The sensor assembly includes an inertial mass coupled to the module case, and at least one seismic sensor coupled to the inertial mass. An isolation layer is coupled to the module case and the sensor assembly such that the sensor assembly remains substantially motionless relative to the module case when an input force of less than a predetermined level is applied to the module case.

A method of isolating one or more seismic sensors in a seismic sensor assembly from high-g shock loads while maintaining sensitivity to seismic waves is provided in another aspect of the present invention. The method comprises providing a housing for the seismic sensor assembly, installing one or more seismic sensors in the housing, and providing an isolator between the one or more sensors and the housing.

Brief Description of the Drawings

The novel features of this invention, as well as the invention itself, will be best understood from the attached drawings, taken along with the following description, in which similar reference characters refer to similar parts, and in which:

Figures 1A and 1B show a seismic sensor module according to the present invention.

Figures 2A and 2B are elevation views of a sensor electronics package suitable for use in the sensor module of **Figure 1A**.

Figure 3 is an exploded view of the sensor assembly of **Figure 2A**.

Figure 4 is an elevation view of the host assembly of **Figure 2A**.

Figure 5 illustrates the module cap of **Figure 1B**.

Detailed Description of the Invention

Figures 1A and 1B show a seismic sensor module according to the present invention. The sensor module **110** includes a module case **112** coupled to a module cap **114**. The module cap **114** provides an access into the module case **112** for one or more electrical conductors **108** of a telemetry cable **118**. The module cap **114** is shown connected to the module case **112** in **Figure 1A**. The module cap **114** is shown unconnected in **Figure 1B**. The telemetry cable **118** is coupled to the module cap **114** by known methods. Housed in the module case **112** and module cap **114** is a sensor electronics package **116**, which will be described in more detail later with respect to **Figures 2-4**.

In a preferred embodiment, the module case **112** is made from polybutylene terephthalate ("PBT"). Alternatively, the module case may be manufactured from any other suitable material such as a plastic, a metal or a

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metal alloy. The module case **112** has a tapered outer surface **126** to provide a compressed fit with the ground while minimizing the effort needed to deploy and retrieve the sensor module **110**.

In one embodiment, the module case **112** is constructed with a wall thickness that allows for wall flexure to provide damping of high-g shock input. The outer surface **126** may include a longitudinal ridge **128**. The longitudinal ridge **128** provides a key-type fit to prevent inadvertent rotation after the sensor module **110** is inserted into the ground.

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The module cap **116** may be constructed using materials substantially similar to those used to construct the module case **112**. In a preferred embodiment, the module cap **114** and module case **112** provide a hermetic seal when coupled.

A module tip **120** is coupled to a distal end of the module case **112**. The module tip **120** preferably is substantially conical in shape or otherwise tapered for ease of insertion into the earth. The sensor electronics package **116** and module tip **120** are mechanically and electrically coupled to one another with an insert **117**. The insert **117** is preferably integral to the module case **112** and manufactured from an electrically conductive material to provide the electrical coupling. In one embodiment, the insert **117** includes a threaded exterior surface **122** for coupling to a complementary threaded interior surface **124** of the module tip **120**.

Disposed between the module tip **120** and the sensor electronics package **116** is an isolator **115** for isolating the sensor electronics package from damaging

mechanical shock axially induced in the sensor module **110**. The isolator **115** may comprise one or more layers **115a** and **115b** of vibration-isolating material. In one embodiment, a first isolating layer **115a** adjoins the electronics package **116** and a second isolating layer **115b**. The second isolating layer **115b** adjoins the first isolating layer **115a** and the module tip **120**. In one embodiment the first isolating layer **115a** is manufactured from a material such as silicone, and the second isolating layer **115b** is manufactured from a material such as a high-damping polyurethane foam. A second, and similarly constructed isolator **130** is disposed between the sensor electronics package **116** and the module cap **114**.

The sensor electronics package **116** and the isolators **115** and **130** are placed in slight compression when assembled inside the module case **112**. Movement of the sensor electronics package **116** is constrained by an interior surface of the module case **112** and by the module cap **114** and tip **120** to provide limited movement in three translational and three angular axes.

Figures 2A and 2B illustrate the sensor electronics package **116**. The sensor electronics package **116** includes a sensor assembly **222** and a host assembly **224**. The sensor assembly **222** and the host assembly **224** each preferably comprise four sides. A horizontal isolator **228** and a side cap **226** are coupled to each side of the respective assemblies **222** and **224**. Each horizontal isolator **228** may be made from a high-damped polyurethane foam material however.

Each side cap **226** is preferably made from a thermoplastic material. Alternatively, the side caps **226** may be constructed using any suitable material.

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Each side cap **226** has a tapered outer surface to interface with an internal tapered surface of the module case **112** (see **Figur 1A**). The electronics package **116** and the horizontal isolators **228** are in compression when the sensor module **110** is assembled and substantially all of the electronics package **116** is surrounded by a layer of isolating material formed by the several horizontal isolators **228** and end isolators **115 and 130**.

Suitable fasteners such as screws **232** are used to secure the side caps **226** to the sensor assembly **222** and to the host assembly **224**. As shown, it is preferred to provide openings **234** in the horizontal isolators so that the screw heads will pass through the horizontal isolators **228**. In this fashion, the screws **232** mechanically secure the side caps **226** without interfering with the isolating properties of the horizontal isolators **228**.

A ground lead **227** electronically couples the host assembly **224** to a ground spring **229**. The ground spring **229** contacts the insert **117** (see **Figure 1a**) when the sensor module **110** is assembled, thus creating a direct electrical path to ground from the host assembly **224**.

In the embodiment shown in **Figures 2A** and **2b**, the sensor assembly **222** and the host assembly **224** are mechanically attached to each other. Alternatively, their structures may be separated to accommodate various module shapes. Alternatively, the horizontal isolators **228a-d** may be constructed with any suitable damping material.

The sensor assembly **222** includes one or more sensors **230a-c**. The sensors **230a-c** will be described in more detail with respect to the embodiment shown in **Figures 3A** and **3B**.

Figure 3 shows the sensor assembly **222** of **Figure 2A**. The sensor assembly **222** includes sensors **230a, 230b, and 230c** mounted on sensor boards **332a, 332b, and 332c**. The sensor boards **332a-c** are attached to a block **334**, to a connector board **336** and to a regulator board **338**. A standoff **340** is used for added stability for the boards **332a-c and 338**. The sensors **230a-c** are preferably MEMS accelerometers. The block **334**, sometimes referred to as an inertial mass, is preferably made from aluminum and is machined so that the sensors **230a-c** have substantially orthogonal axes of sensitivity. The mass of the block **334** provides noise reduction and abatement during operation of sensor module **110**. The inertia of the mass helps damp resonance tones caused by the natural frequency of the sensor module structure.

Alternatively, the block **334** may be constructed in another shape to allow for a specific desired sensor module diameter or to adjust the mass of the sensor assembly **222**. Also, the block may be shaped to provide non-orthogonal axes of sensitivity.

The host assembly **224** is illustrated with more detail in **Figure 4**. The host assembly **224** includes a telemetry board **438**, a controller board **440**, and a power supply board **442**. The boards **438, 440 and 442** are electrically coupled to a telemetry interface board **444**. Any fastener **446** known in the art may be used to mechanically couple the several boards **438-444**.

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Referring now to **Figure 1B and Figure 5** the module cap **114** of **Figure 1B** will be described in more detail. **Figur 5** is a cross section view of the module cap **114** and telemetry cable **118**. The module cap **114** includes an end cap **546**. The end cap **546** has a rope handle **552** connected thereto as a handle to aid in deployment and retrieval of the sensor module **110**. The telemetry cable **118** terminates at a feedthrough **548** formed in the end cap **546**. The feedthrough **548** preferably is a bulkhead feedthrough connector with sealed contacts having a seal around the connector diameter to prevent the intrusion of water into the sensor module **110**. An overmold **550** prevents water intrusion into the telemetry cable **118** and provides strain relief for the telemetry cable **118**. When assembled, the sensor module **110** is preferably a hermetically sealed unit.

The several embodiments of the present invention described above and shown in **Figures 1A-5** reduce sensor module sensitivity to shock loading, and improve accelerometer alignment. The invention described preferably includes an orthogonal arrangement of three MEMS accelerometers. The accelerometers are mounted precisely within a module case to maintain their relative orientation within a predetermined alignment specification. Additionally, an isolation system has been described that provides protection for the sensors from high-g shock loads while maximizing coupling to sub-g inputs. The isolation aspect includes a combination of rigidity, internal damping, and allowable travel. The isolation aspect of the invention further includes an inertial mass coupled to the sensors for noise abatement during operation caused by sensor module resonance.

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The embodiments described above by way of example do not limit the scope of the invention or prevent other embodiment developed by those skilled in the art with the benefit of this disclosure from being within the scope of the invention. For example, other module designs or deployment methods may be used as particular requirements dictate.

In an alternative embodiment, the cable **118** shown in **Figure 5** may be located on the top of the module cap **114** to provide and axially-oriented feedthrough.

In another embodiment (not shown) of the invention, a box-shaped module instead of the shown cylinder-shaped module may be advantageous. The box module may have all electronics in a box. The box would have spikes on a bottom side for coupling the box module to the ground.

The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope and the spirit of the invention. It is intended that the following claims be interpreted to embrace all such modifications and changes.